

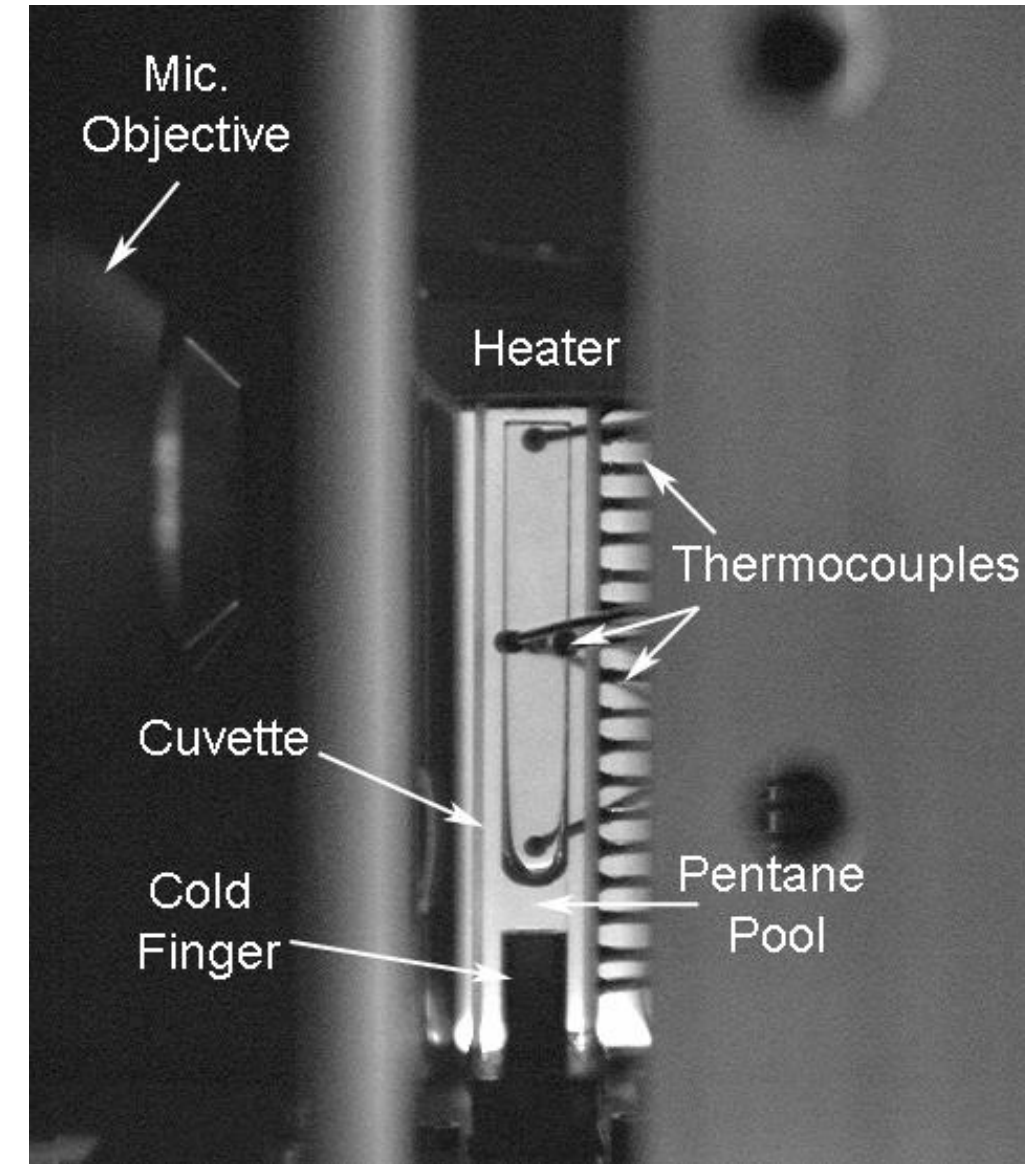


The Constrained Vapor Bubble Experiment – Interfacial Flow Region

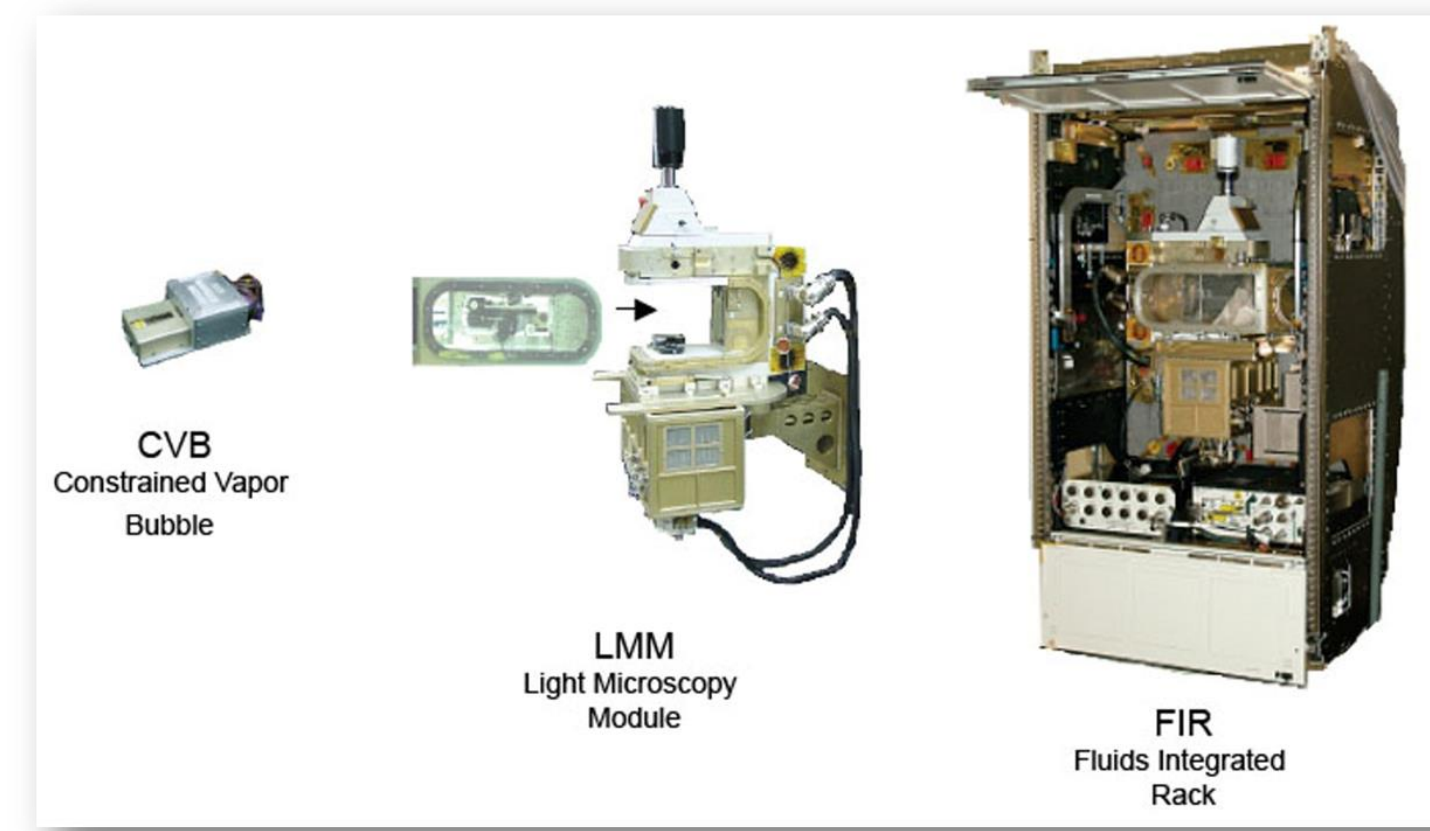
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Introduction



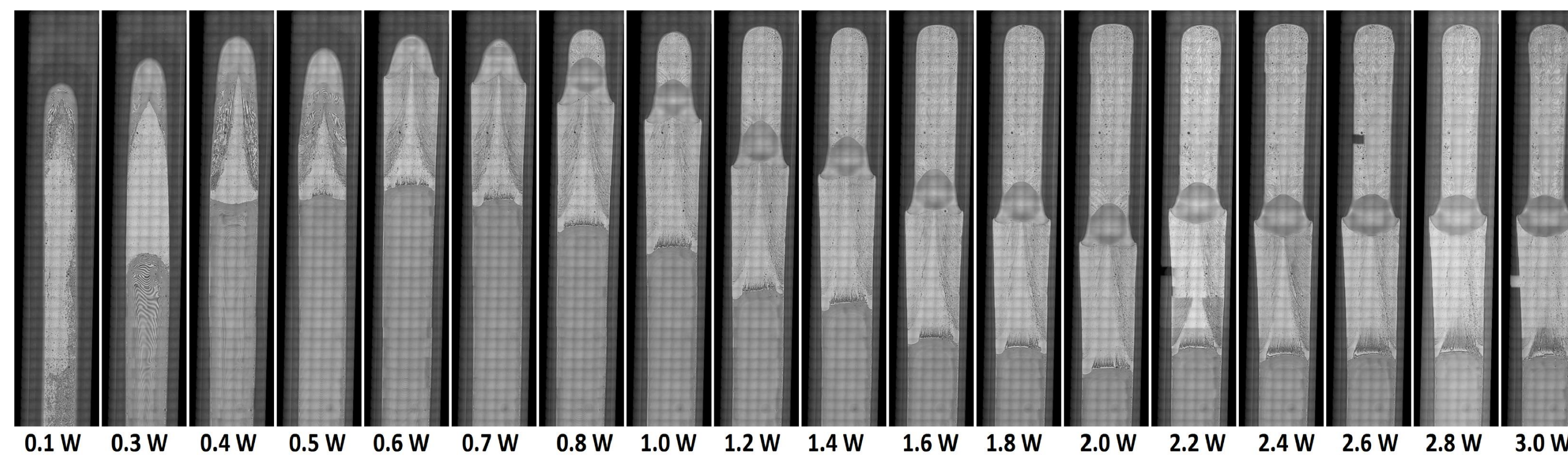
Surveillance Image



Experimental set-up

- A bubble constrained by the walls of a solid.
- A transparent wickless heat pipe flown in the ISS
- 3mm x 3mm ~ 20 - 40 mm long (inside dimensions), size developed to have low Bond number.
- Study the fluid physics and determine the liquid and vapor distribution.
- Completely modular design.

Experimental Results



Composite image 40 mm μ g run

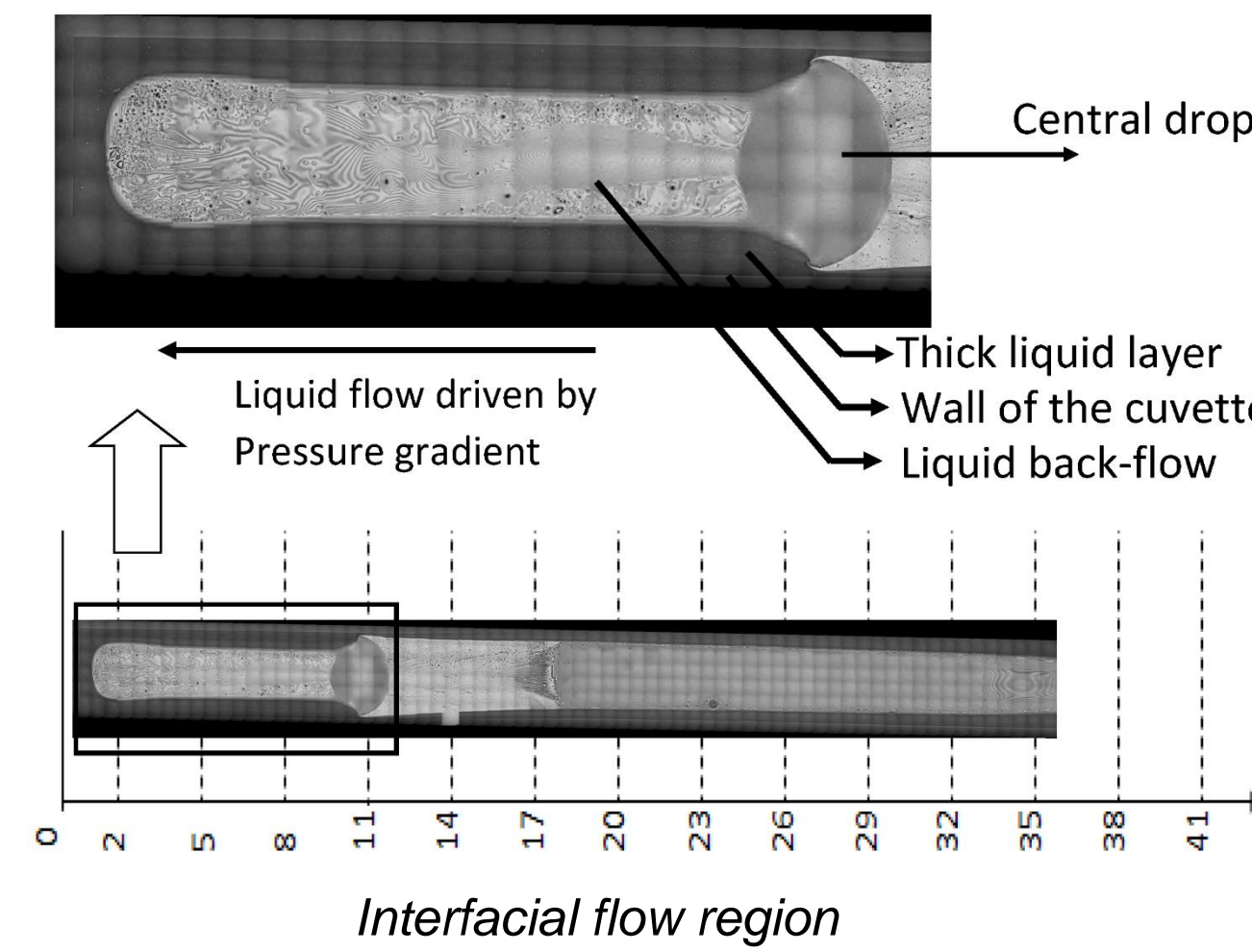
- Heat pipes are predicted to dry-out as power is increased. [1-2]
- Opposite behavior of dry-out i.e. flooding observed at heater end from 0.7W onwards in microgravity [3].
- Formation of a thick layer of liquid near heater starts from 0.7 W – 3 W called Interfacial flow region
- Beyond 2.2 W, the interfacial region reaches a constant length, arresting further penetration of liquid down the axis of the heat pipe.

Experimental Results

Higher Temperature
Lower surface tension

Marangoni flow
driven by surface
tension gradient

Low Temperature
High surface tension

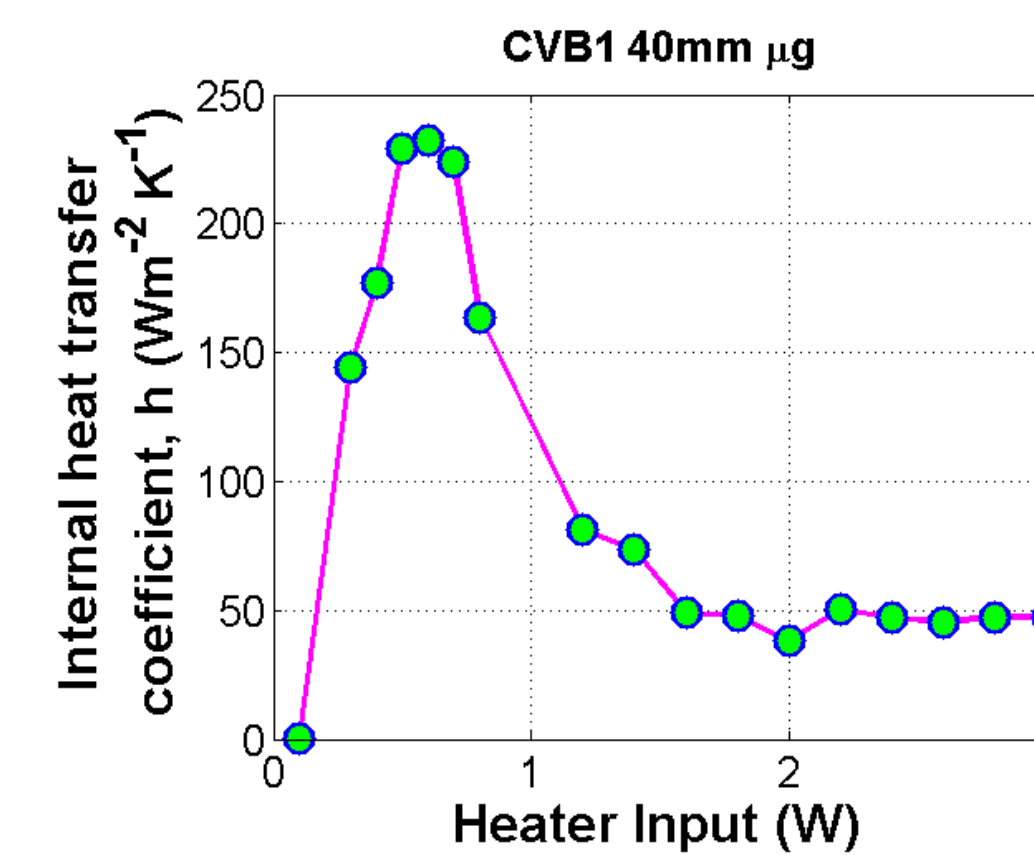


- The Marangoni stress forces liquid from the heater end to the cooler end.
- Capillary pumping forces liquid from the cooler end to the heater end.
- The flow combination leads to a pinch point and a central drop that collects the excess liquid.
- Increase in vapor space at 3 W hints at a new operation regime.

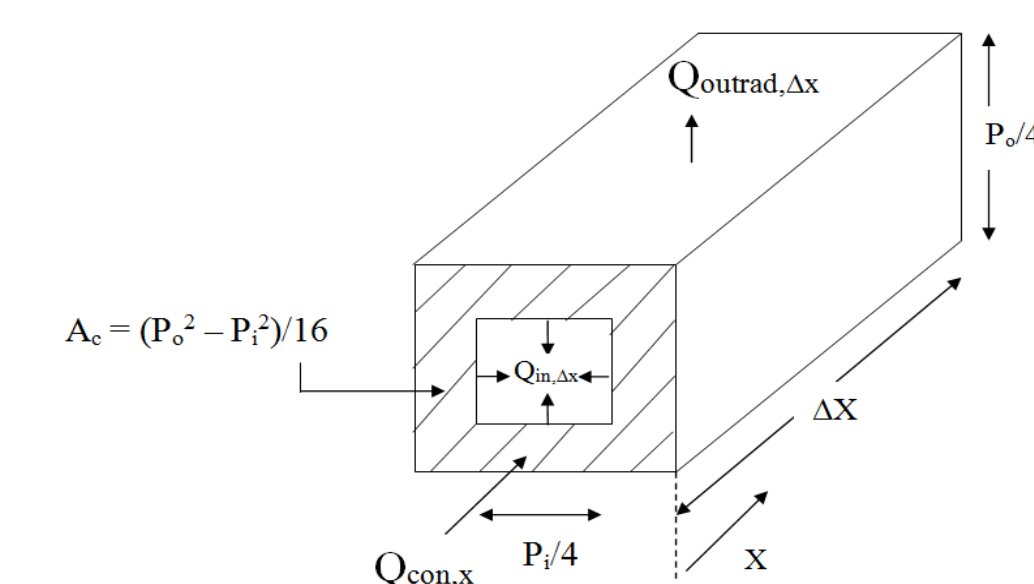
- Extra heat input is compensated by back flow and then evaporation of liquid in the vapor region.

Mathematical Analysis

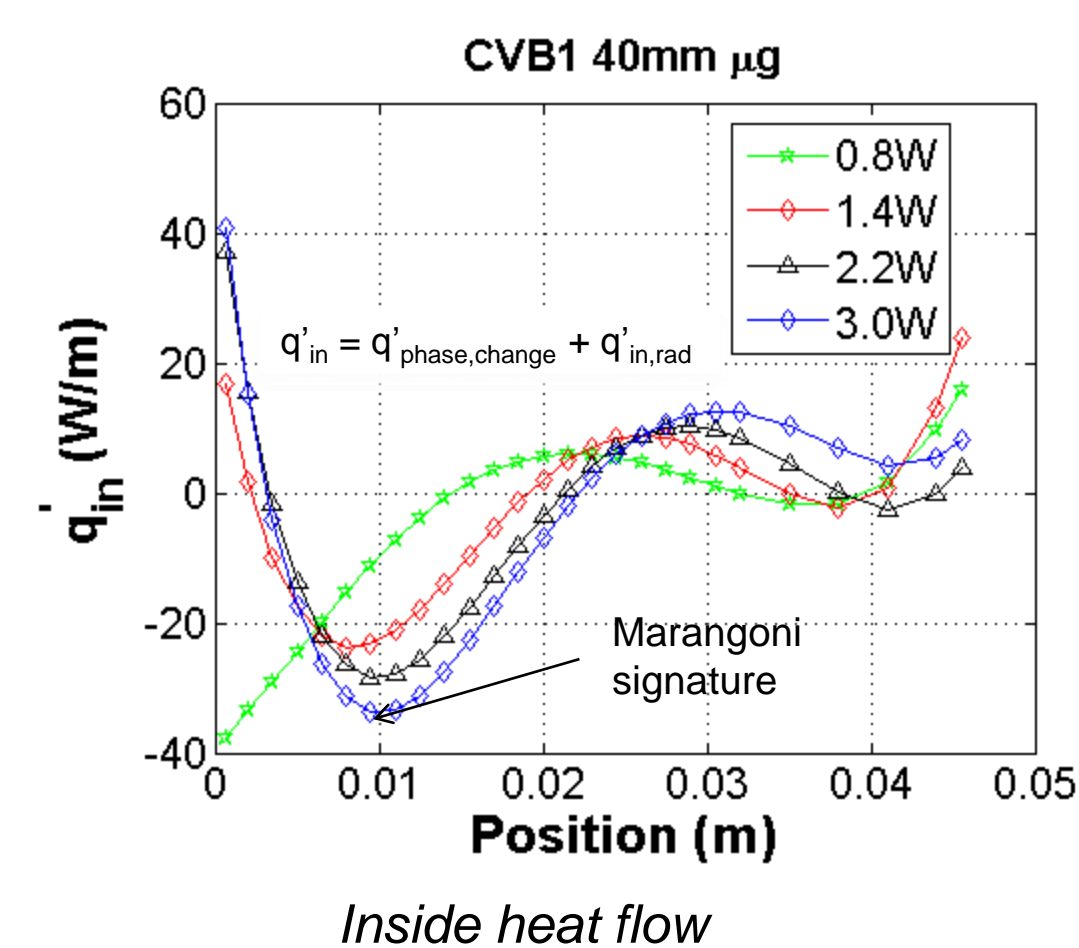
$$k_{silica} A_{silica} \frac{dT}{dx} - h_{inside} P_{inside} (T - T_{vapor}) - \sigma \epsilon_{silica} P_{outside} (T^4 - T_{surroundings}^4) = 0 \quad (1)$$



1D model for heat flow [4]



$$q'_{in} = q'_{cond} + q'_{outrad} \quad (2)$$



- Maximum internal heat transfer coefficient at 0.7 W
- Interfacial flow starts from 0.7 W, results in increased resistance to heat transfer and thus, decrease in internal heat transfer coefficient.
- A constant internal heat transfer coefficient from 2.2 – 3W is consistent with the arresting of interfacial flow region.
- Bending curve near the heater end - a signature of 'Interfacial flow region'.
- The Marangoni signature coincides well with the location of central drop at high power inputs.
- Beyond 2.2 W heat input, the temperature gradient at 10-12 mm of heat pipe is not sufficient to offset the capillary flow and movement of the junction vortex down the axis is arrested.
- Increased heat input is dissipated to the surroundings as outside radiation.
- A balance between an increased evaporation rate due to thick liquid film and outside radiation results in a constant heat transfer coefficient.

Conclusions

- The internal heat transfer coefficient of the CVB can be correlated to the presence of the Interfacial flow region.
- The competition between capillary and Marangoni flows causes 'Flooding' near the heater and not a 'Dry-out' region.
- The growth of the interfacial flow region growth is arrested at higher power inputs.
- 1D heat model confirms the presence of 'Interfacial flow region' and its growth.
- Visual observations are essential to understanding the heat pipe's performance.

References

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2. Yang, L., and Homsy, G. M., "Steady three-dimensional thermocapillary flows and dryout inside a V-shaped wedge", *Phys. Fluids*, 18, 042107, (2006).
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Future Work

- Understand the role of cooler temperature on the growth of the interfacial flow region and the magnitude of the interfacial forces
- Develop higher dimension model to predict the interface temperature gradient and the velocity profile in the interfacial flow region.
- Improve theoretical models [1,2] to predict the flooding behavior observed in CVB experiments.

Final goal is to cool critical space craft components to enable long-term manned missions.

Applications

- LED lamps, Desktops, laptops.
- Hubble Space Telescope, Mars Rovers.
- Very important for space applications.

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